Dual-energy CT behavior of heroin, cocaine, and typical adulterants

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Abstract: PURPOSE: To investigate the dual-energy CT behavior of cocaine and heroin and of typical adulterants, and to evaluate the elemental composition of pure cocaine and heroin compared with cocaine and heroin in bodypacks. METHODS: Pure heroin and pure synthetic cocaine samples, eight different adulterants, and in each case ten different bodypacks containing cocaine or heroin, were imaged at 80, 100, 120, and 140 kVp in a dual source CT system at two different degrees of compression. Two radiologists, blinded to the samples, measured the attenuation. The dual-energy index (DEI) was calculated. We performed atomic mass spectrometry for the elemental analysis of pure cocaine, pure heroin, and heroin and cocaine in bodypacks, and 140 kVp in a dual-source CT system. RESULTS: Inter- and intra-observer agreement for attenuation measurements was good ($r = 0.61$-0.72; $p < 0.01$). The cocaine bodypacks had a positive DEI of 0.029, while the pure drugs and the heroin bodypacks had a negative DEI (-0.051 to -0.027). Levamisole was the only substance which expressed a positive DEI of 0.011, while the remaining adulterants had negative DEIs ranging between -0.015 and -0.215. Atomic mass spectrometry revealed a concentration of tin in the cocaine bodypack that was 67 times higher than in the pure synthetic cocaine sample. CONCLUSIONS: The different DEIs of bodypacks containing cocaine and heroin allow them to be distinguished with dual-energy CT. Although the material properties of pure cocaine, pure heroin, or common drug extenders do not explain the differences in DEI, tin contamination during illicit natural cocaine production may be a possible explanation.

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ORIGINAL ARTICLE

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Results Inter- and intra-observer agreement for attenuation measurements was good ($r = 0.61$–0.72; $p < 0.01$). The cocaine bodypacks had a positive DEI of 0.029, while the pure drugs and the heroin bodypacks had a negative DEI (-0.051 to -0.027). Levamisole was the only substance which expressed a positive DEI of 0.011, while the remaining adulterants had negative DEIs ranging between -0.015 and -0.215. Atomic mass spectrometry revealed a concentration of tin in the cocaine bodypack that was 67 times higher than in the pure synthetic cocaine sample.
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Keywords Dual-energy CT · Bodypack · Cocaine · Heroin · Adulterants

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Introduction

The diagnostic standard for detecting ingested drug containers is plain film radiography of the abdomen, which is quick and inexpensive. This method is, however, very insensitive in the presence of scybala, calcification, intestinal air, and other foreign bodies [1]; it is particularly insensitive for the detection of small containers, with a reported sensitivity of only 58 % [2]. Computed tomography (CT) has been found to be a highly accurate imaging modality for the detection of bodypacks, with a sensitivity of 100 % and a specificity of 94 % [2]. At the present time, CT is often performed only when there is a strong suspicion of bodypacking but negative or uninterpretable initial abdominal radiography, in traffickers with suspected intoxication from

either leakage or rupture of a drug package, and in cases of suspected bowel obstruction [3]. The restricted use of CT in the work-up of suspected traffickers is mainly due to its higher radiation exposure compared with plain film radiography, which limits its use in the frequently young and healthy traffickers. Low-dose CT protocols with a mean estimated effective radiation dose of 2.2 mSv [4] have therefore been introduced for the detection of bodypacks, giving an exposure close to that of abdominal plain films.

Differentiation of cocaine and heroin with CT has been performed by measuring the attenuation values of drug containers in Hounsfield units (HU) [4–9]. However, relying on attenuation measurements alone is limited by various factors influencing this parameter [3, 5]. Most recently, dual-energy CT has been introduced to differentiate packages containing cocaine and heroin [9]. The dual-energy index (DEI) is calculated with the attenuation information from two different energy levels and can be used to differentiate substrates—an established clinical approach used, for example, to classify urinary stones [11, 12]. In a recent phantom study, the DEI was shown to be highly accurate for differentiating packages containing cocaine and heroin [10]. However, it remains unclear whether the difference in the DEIs of cocaine- and heroin-containing packages is caused by the drugs themselves or the impact of other substances in the bodypacks. In addition, it is unclear how the compression of drugs in the bodypacks influences material behavior at different energy levels.

The purpose of this study was to investigate the dual-energy behavior of cocaine and heroin and of typical adulterants, with different degrees of compression, and to evaluate the elemental composition of pure cocaine and heroin compared with cocaine and heroin in bodypacks.

Materials and methods

Specimen and sample preparation

Based on data in the literature [13] and the chemical analysis of bodypacks obtained from the national border control agency, the following typical adulterants were purchased:

- levamisole (analytical standard, Sigma-Aldrich Chemie GmbH, Steinheim, Germany);
- lidocaine (Sigma-Aldrich Chemie GmbH, Steinheim, Germany);
- lactose (Ph. Eur., anhydrous, Sigma-Aldrich Chemie GmbH, Steinheim, Germany);
- saccharose (>99.0 %, ACS reagent, Sigma-Aldrich Chemie GmbH, Steinheim, Germany);
- diltiazem (>99 % HPLC, Sigma-Aldrich Chemie GmbH, Steinheim, Germany);
- paracetamol (Sigma-Aldrich Chemie GmbH, Steinheim, Germany);
- caffeine (ReagentPlus, Sigma-Aldrich Chemie GmbH, Steinheim, Germany);
- phenacetin (Sigma-Aldrich Chemie GmbH, Steinheim, Germany).

In addition, pure heroin (Diamo Narcotics GmbH, Thun, Switzerland), pure synthetic cocaine (Haeusler AG, Duggingen, Switzerland) and, in each case, ten samples of heroin and cocaine bodypacks obtained from different drug traffickers were also tested.

Ten milliliters of each powdered sample were filled into capped plastic syringes (B. Braun Melsungen AG, Melsungen, Germany) and scanned with two different degrees of compression (1—light compression, no visible remaining air, 2—greatest possible manual compression).

CT acquisition

The syringes were placed in the center of a dual-source 64-detector row CT system (Somatom Definition, Siemens Healthcare, Forchheim, Germany) and imaged using the following parameters: detector collimation 32 × 0.6 mm; slice acquisition 64 × 0.6 mm; gantry rotation time 330 ms; and a pitch factor of 0.5. Each syringe was scanned four times at each compression, using the following tube voltage/tube current time product settings:

(a) Tube voltage 80 kVp, tube current–time product 425 mAs
(b) Tube voltage 100 kVp, tube current–time product 190 mAs
(c) Tube voltage 120 kVp, tube current–time product 112 mAs
(d) Tube voltage 140 kVp, tube current–time product 75 mAs

The tube currents were adjusted to yield a constant CT volume dose index of 8.0 mGy for all protocols.

The data were reconstructed with a slice thickness of 1.0 mm at 0.7 mm increments, using a medium soft-tissue convolution filter (B30f). The image datasets were anonymized for the acquisition parameters (i.e., acquisition mode, tube voltage, tube current time-product, and convolution filter) and transferred to a dedicated workstation for further data analysis.

CT analysis

Two radiologists (each with more than 10 years of experience in CT imaging) evaluated all CT scans; they were blinded to the acquisition parameters and the specific contents of the syringes. The CT studies were presented to both radiologists in random order.

The two observers independently performed a quantitative analysis of the CT attenuation of the syringes by placing a region of interest (ROI) in each container and performing the measurements five times on consecutive slices. The size of the ROI was manually adjusted to cover at least 60 % of the container's cross-section, carefully avoiding air and crystallization areas within the specimen, as described previously [10].

The DEI was calculated from the attenuation values at 80 and 140 kVp using Eq. 1:

$$\mathrm{DEI} = \frac{\mathrm{CT\,attenuation}_{80\,\mathrm{kVp}} - \mathrm{CT\,attenuation}_{140\,\mathrm{kVp}}}{\mathrm{CT\,attenuation}_{80\,\mathrm{kVp}} + \mathrm{CT\,attenuation}_{140\,\mathrm{kVp}} + 2000} \quad (1)$$

Atomic mass spectrometry

Multi-element determinations of one sample of a cocaine bodypack, pure synthetic cocaine, a heroin bodypack, and pure heroin were performed using inductively coupled plasma mass spectrometry (ICP-MS; 7700 Series, Agilent, Palo Alto, USA). The cocaine and heroin bodypacks selected showed average dual-energy behavior, indicating a representative distribution of elements in these particular bodypacks.

Powdered samples (5 mg) were dissolved with 1 ml nitric acid (2 %; Suprapur, Merck, Darmstadt, Germany) and sonicated for 10 min. The solution was diluted (1:10) to an acidic solution using butanol 0.5 % (GPR Rectapur, VWR International, Nyon, Switzerland), nitric acid 1 %, triton X-100 0.1 % (Sigma-Aldrich, Buchs, Switzerland), indium, and rhodium internal standards (1 µg/l; Agilent, Palo Alto, USA). Simultaneous semi-quantitative determination of a panel of 64 elements was performed on each sample (see "Appendix").

Statistical analysis

All statistical analysis was performed using IBM SPSS Statistics (release 20, Chicago, IL, USA) and MedCalc software (MedCalc 9.0.2, Mariakerke, Belgium). A p level of <0.05 was taken to be statistically significant. Numerical variables were expressed as means ± standard deviations. Inter- and intra-observer agreement on measurement of CT attenuation within the drug container was assessed using Pearson's correlation.

Results

Intra-observer and inter-observer agreement

There was good intra-observer agreement for the CT attenuation measurements by reader #1 (Pearson: $r = 0.61$; $p < 0.01$) and reader #2 (Pearson: $r = 0.72$; $p < 0.01$), and a good inter-observer agreement between the two readers (Pearson: $r = 0.63$; $p < 0.01$). The averages of the CT attenuation measurements from both observers were used for further analysis.

Influence of the degree of compression on dual-energy behavior

With grade 2 compression, all drug and adulterant samples investigated showed a noteworthy dual-energy effect (DEI different from zero), while grade 1 compression had only a minor effect (Table 1). Grade 2 compression samples were therefore used for further analysis.

Dual-energy behavior of the different drugs and adulterants

The dual-energy behavior of the different drugs and adulterants is summarized in Table 1 and in Figs. 1 and 2. The heroin bodypacks had higher attenuation values with increasing tube voltage (DEI = −0.046) while cocaine bodypacks showed lower attenuation values with increasing tube voltage (DEI = 0.029). Pure heroin demonstrated effects similar to the heroin-containing bodypacks, with a DEI of −0.051. Pure synthetic cocaine also gave a negative DEI (DEI = −0.027), exhibiting the opposite behavior to that of the cocaine-containing bodypack.

For the eight adulterants tested, levamisole was the only substance which expressed a slightly positive DEI of 0.011, while the remaining adulterants had negative DEIs ranging between −0.015 and −0.215.

Elemental composition of pure synthetic drugs and bodypacks

Compared with the pure synthetic cocaine sample, ICP-MS of the cocaine bodypack found a concentration of cerium seven times higher, a concentration of beryllium nine times higher, a concentration of arsenic ten times higher, and a concentration of tin 67 times higher. The other elements showed a comparable distribution in all samples. The detailed distribution of the elements investigated is shown in the "Appendix".

In order to validate the effects of tin on the DEI, a CT scan with similar parameters to those described above was performed on an admixture of pure synthetic cocaine with tin-IV-oxide (nanopowder, Sigma-Aldrich Chemie GmbH, Steinheim, Germany) in a final concentration of 4 to 1,000,000. The resulting DEI of the pure synthetic cocaine/tin oxide sample was 0.025, very close to the DEI of the cocaine bodypacks (DEI = 0.029; Fig. 3).

Table 1 Attenuation of drugs and adulterants at different tube voltages and resulting dual-energy index

Substance	x_{80kVp} [HU]	x_{100kVp} [HU]	x_{120kVp} [HU]	x_{140kVp} [HU]	$x_{140} - x_{80}$	DEI
Heroin bodypacks	−667 ± 17/−226 ± 17	−660 ± 23/−175 ± 15	−661 ± 28/−159 ± 13	−658 ± 22/−151 ± 11	9 ± 14/75 ± 8	−.013/−.046
Pure heroin	−570 ± 19/−258 ± 8	−562 ± 14/−218 ± 7	−564 ± 15/−195 ± 11	−560 ± 22/−178 ± 9	10 ± 17/80 ± 10	−.012/−.051
Cocaine bodypacks	−480 ± 24/−42 ± 12	−475 ± 27/−57 ± 15	−483 ± 19/−76 ± 9	−487 ± 17/−85 ± 10	−7 ± 20/−43 ± 9	.006/.029
Pure cocaine	−510 ± 12/−159 ± 8	−504 ± 12/−135 ± 7	−502 ± 14/−123 ± 10	−496 ± 16/−112 ± 6	14 ± 15/47 ± 9	−.014/−.027
Diltiazem	−471 ± 11/−316 ± 5	−450 ± 13/−175 ± 13	−441 ± 12/−159 ± 13	−430 ± 17/−151 ± 9	41 ± 14/165 ± 11	−.037/−.107
Phenacetin	−741 ± 11/−617 ± 8	−702 ± 13/−531 ± 23	−691 ± 11/−437 ± 26	−666 ± 15/−408 ± 16	75 ± 12/209 ± 18	−.126/−.214
Lidocaine	−655 ± 14/−404 ± 10	−616 ± 21/−319 ± 27	−602 ± 12/−278 ± 14	−593 ± 14/−254 ± 15	63 ± 15/150 ± 19	−.082/−.112
Caffeine	−633 ± 17/−502 ± 24	−601 ± 15/−304 ± 27	−580 ± 15/−260 ± 26	−582 ± 17/−230 ± 18	51 ± 15/272 ± 24	−.065/−.215
Saccharose	−348 ± 22/−171 ± 24	−344 ± 14/−156 ± 8	−337 ± 12/−136 ± 7	−339 ± 14/−128 ± 8	9 ± 11/43 ± 9	−.007/−.025
Levamisole	−252 ± 14/−51 ± 11	−250 ± 11/−72 ± 6	−255 ± 12/−76 ± 6	−261 ± 10/−83 ± 6	−9 ± 12/−32 ± 10	.006/.011
Lactose	−358 ± 13/−159 ± 9	−362 ± 14/−143 ± 7	−350 ± 12/−139 ± 12	−345 ± 11/−128 ± 6	13 ± 10/31 ± 9	−.010/−.018
Paracetamol	−579 ± 22/−269 ± 19	−585 ± 14/−259 ± 7	−581 ± 14/−252 ± 14	−575 ± 16/−247 ± 15	12 ± 15/22 ± 13	−.005/−.015

The values given are: value at compression grade 1/value at compression grade 2

x_{80kVp}, attenuation at 80 kVp; x_{100kVp}, attenuation at 100 kVp; x_{120kVp}, attenuation at 120 kVp; x_{140kVp}, attenuation at 140 kVp; $x_{140} - x_{80}$, difference between attenuation at 140 kVp and at 80 kVp; DEI, dual-energy index

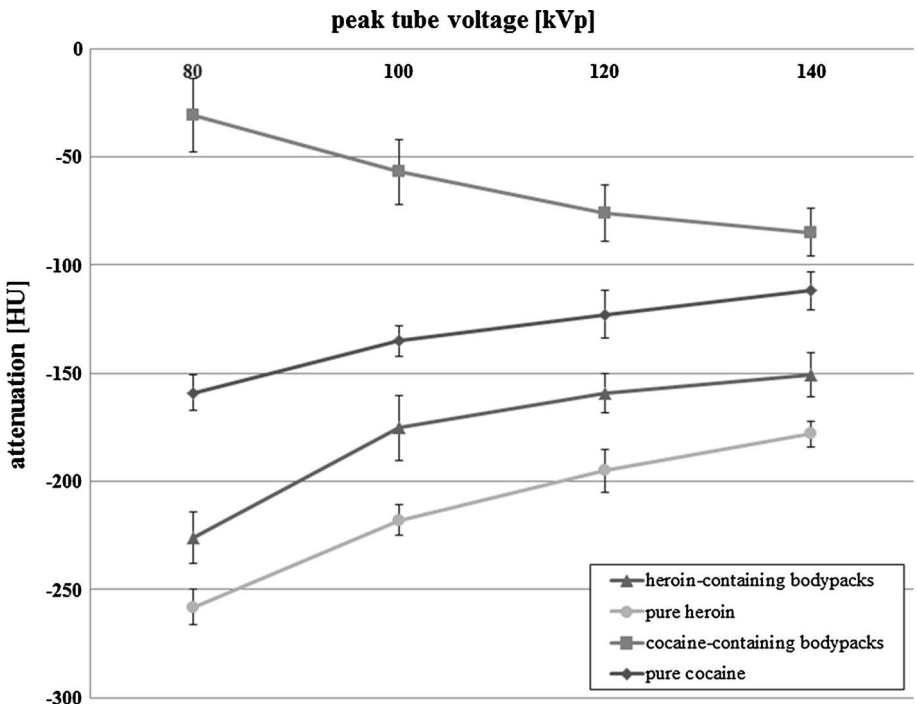

Fig. 1 Plot of the mean CT attenuation values of pure synthetic and illicit cocaine and heroin at different tube voltages. Whiskers demonstrate the standard deviation of the mean. There is a trend for cocaine bodypacks to lower attenuation values with increasing tube voltage while pure synthetic cocaine, pure heroin and heroin bodypacks demonstrate higher attenuation with increasing tube voltage

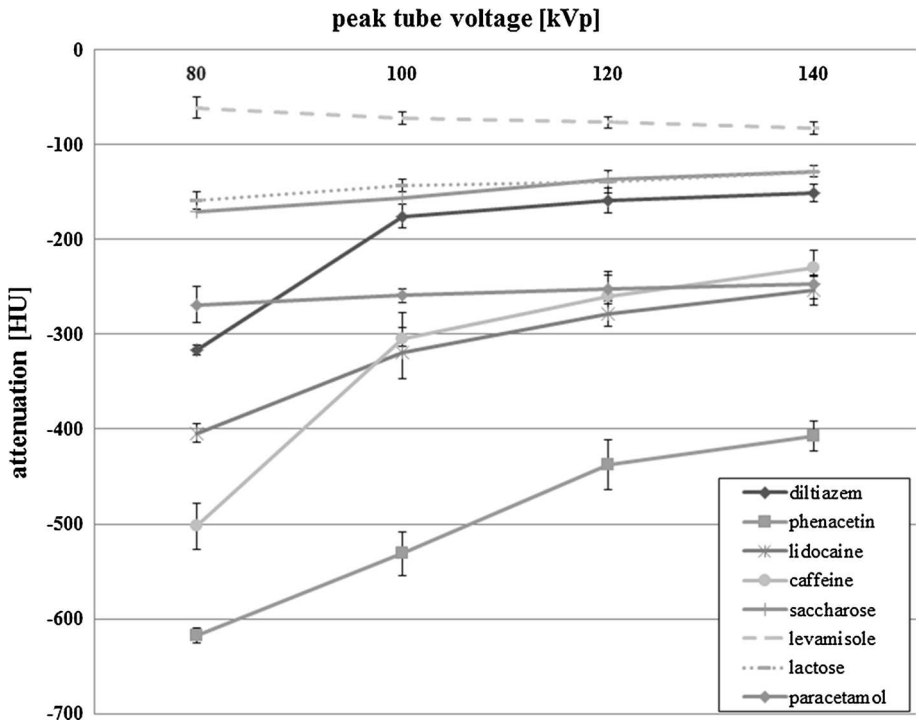

Fig. 2 Plot of the mean CT attenuation values of typical adulterants at different tube voltages. Whiskers demonstrate the standard deviation of the mean. There is a trend for levamisole to have lower attenuation values with increasing tube voltage, while the remaining adulterants demonstrate higher attenuation with increasing tube voltage

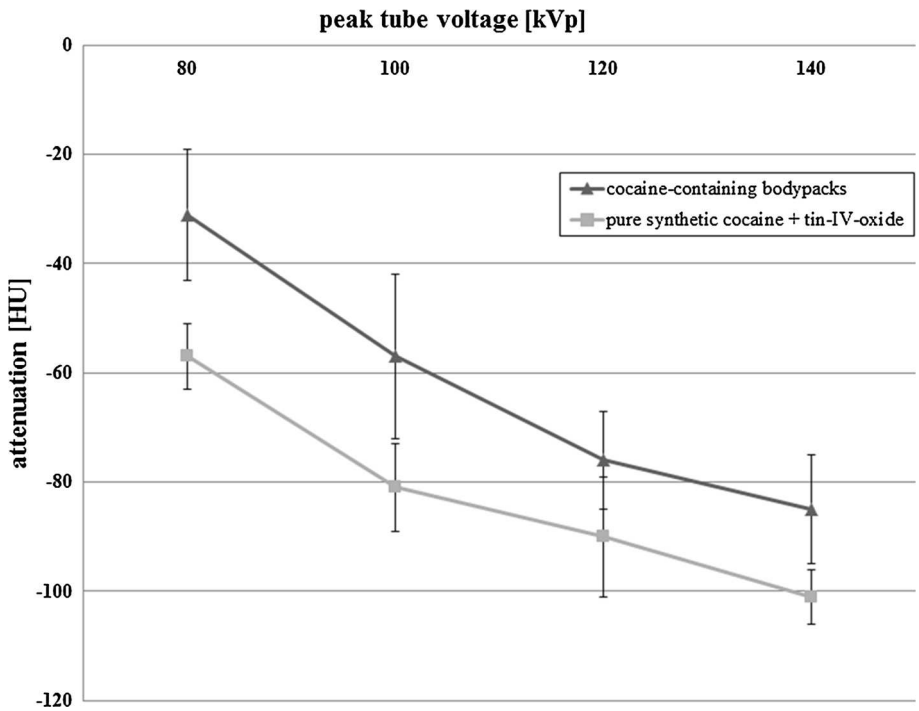

Fig. 3 Plot of the mean CT attenuation values of illicit cocaine and an admixture of a sample of synthetic cocaine with tin-IV-oxide in a final concentration of 4–1,000,000 at different tube voltages. Whiskers demonstrate the standard deviation of the mean. Cocaine-containing bodypacks and the admixture demonstrate similar trends to lower attenuation values with increasing tube voltage

Discussion

In a recent study, bodypacks containing heroin and cocaine demonstrated opposing trends in the DEI [10]. In this study, we postulated that the DEI could be used as a CT parameter for differentiating bodypacks, as the DEI should be affected only by the material behavior of the drug and the accompanying substances and not by the degree of compression. In the present study, we found a remarkable dual-energy effect in all samples under a greater degree of compression, while light compression caused only a minor dual-energy effect. While compression of drugs in

bodypacks does not influence the effective atomic number of the material or the material behavior at different energy levels, it does affect the amount of air present. More air in loosely compressed packs can even out the dual-energy effect of the investigated material, since the radiodensity of air is defined as −1,000 HU, irrespective of the tube voltage. Bodypacks are usually highly compressed and tightly wrapped in order to exploit the smuggler's full capacity, and therefore commonly demonstrate notable dual-energy behavior.

We attempted to determine the reasons for the observed differences in the dual-energy behavior of cocaine and heroin bodypacks. The individual material properties of cocaine and heroin may be one explanation for the observed differences. In our study, however, both pure cocaine and pure heroin demonstrated negative DEIs comparable to the dual-energy behavior of heroin-containing bodypacks. The decrease in the attenuation of cocaine bodypacks at higher tube voltages is not therefore explained by the dual-energy behavior of the cocaine itself.

A second explanation may be the dual-energy behavior of the typical adulterants in cocaine bodypacks. Illicit drug samples are almost always cut with other substances: bulked out with inactive "diluents", such as sugars, to increase the profits or laced with pharmacologically active adulterants to enhance the drug's effects [10, 13]. While heroin bodypacks usually only have paracetamol and caffeine added, cocaine bodypacks are very heterogeneous with respect to sample concentration and composition [13]. The average concentration of cocaine in bodypacks was found to be 48 % in 2010, with a maximum of 10 adulterants detected: phenacetin, caffeine, and levamisole were the most common [13]. In our study, most adulterants demonstrate negative DEIs, and the only extender showing the behavior of cocaine bodypacks is levamisole. However, levamisole has a much lower DEI than the cocaine bodypacks (0.011 and 0.029, respectively). On average, only a small concentration of 4.1 % levamisole is present in cocaine bodypacks [13]. The dual-energy behavior of adulterants does not therefore explain the dual-energy behavior of cocaine bodypacks.

A third explanation may lie in the elemental composition of cocaine bodypacks. The only remarkable finding on atomic mass spectrometry was a higher concentration of tin in the cocaine bodypack, which exceeded the concentration in pure cocaine by a factor of 67. The higher amount of tin may be a possible explanation for the higher attenuation of cocaine bodypacks at lower tube voltage. The dual-energy effect is based on different photon interaction at different tube voltages. Incoherent Compton scattering becomes important at higher tube voltages, and is almost independent of the atomic number. The probability of photoelectric absorption significantly increases with lower tube voltages and higher atomic number. The photoelectric effect is inversely proportional to the third power of the energy level and the fourth power of atomic number. An element with a high atomic number, such as tin ($Z = 50$), can result in the high absorption of photons at a low kVp and would therefore explain the higher absorption of cocaine bodypacks at a low tube voltage. In addition, the dual-energy behavior of a mixture of pure cocaine and tin-IV-oxide correlated to that of the cocaine bodypacks, furnishing evidence of the presumed effects of tin. Contamination with tin in very low concentrations seems to be responsible for the specific dual-energy behavior of cocaine bodypacks.

The source of the tin contamination in illicit natural cocaine can be found in the production process. It is possible to produce illicit synthetic cocaine, obtaining cocaine hydrochloride of >99.5 % purity through numerous crystallization and purification steps. However, synthetic cocaine production requires a high level of expertise and well-equipped laboratory facilities, which are not economically viable in view of the low cost and ready availability of illicit natural cocaine [14]. In contrast to the production of heroin from opium, the production of illicit natural cocaine is commonly entrenched in small industries throughout the coca-producing regions rather than in a clean laboratory setting [14]. Several substances are used during the extraction process. At the present time, two general methods are used for processing coca leaves into coca paste—the solvent extraction and the acid extraction techniques. There are geographical differences in the use of these techniques: the solvent technique is most commonly employed in Peru, Colombia, and Ecuador, while the acid extraction technique is the method of choice in Bolivia [14]. Nonetheless, both techniques use sulfuric acid to convert the free cocaine base into cocaine sulfate. Coca leaves are dusted, moistened, and placed in a maceration pit, which typically consists of a 55-gallon drum or a large metal trough [14]. The simultaneous use of sulfuric acid and metal containers during extraction may be the cause of tin contamination in illicit cocaine samples. Tin is prevalent in several metal alloys and also used for coating steel sheets; it can be dissolved out by exposure to acid. The contamination of illicit natural cocaine with tin seems to be an integral part of the production process not found in the synthetic production of heroin, and this allows cocaine and heroin bodypacks to be distinguished by dual-energy CT.

We have to acknowledge that our study has some limitations. First, we did not investigate all potential adulterants. There may be some drug extenders with positive dual-energy behavior which could add to the dual-energy effect of street cocaine. However, the adulterants typically present in notable amounts in bodypacks were tested in this study, and any cutting agents not investigated should have only a small additional effect on the dual-energy behavior of street cocaine. Second, the elemental determination by mass

spectrometry was not performed on all bodypack samples, although we did investigate samples with an average DEI for each drug type. The elemental composition may therefore be considered as representative for the specific drug. Third, as the bodypack samples were evidence from criminal prosecutions, we did not know their geographical origins. Tin contamination may differ between regions of production and may not be found in all bodypacks.

Conclusions

The different DEIs of cocaine and heroin bodypacks allow differentiation in dual-energy CT. The material properties of pure cocaine, pure heroin, and common drug cutting agents do not explain the differences in DEI. Tin contamination in illicit natural cocaine production may be a possible explanation. In addition, the DEI is higher in compressed drugs. Our results suggest that it would be possible to distinguish between bodypacks containing cocaine and heroin in vivo, but this has to be verified in further studies.

Key points

1. Dual-energy CT permits the differentiation of bodypacks containing cocaine and heroin.
2. Pure synthetic cocaine demonstrates similar dual-energy behavior to pure heroin but cocaine bodypacks do not.
3. Common drug cutting agents or contamination with organic substances does not explain the dual-energy behavior of street cocaine.
4. The dual-energy behavior of street cocaine might be due to contamination with tin during the extraction of cocaine from the coca leaves.

Acknowledgments The authors would like to thank Dr. Meryl Clarke for linguistic improvement of this manuscript.

Appendix

See Table 2.

Table 2 Distribution of elements in the samples of synthetic and street drugs investigated

Element	Pure heroin (ng/mg)	Pure cocaine (ng/mg)	Heroin bodypacks (ng/mg)	Cocaine bodypacks (ng/mg)	Ratio between pure cocaine and cocaine bodypacks
Li	0.12	0.17	0.43	0.35	2.1
Be	6.6	3.2	19	28	8.8
Na	304	329	509	361	1.1
Mg	2.9	3.4	28	4.1	1.2
Al	6.8	2.8	3.8	2.6	0.9
K	55	61	84	61	1.0
Sc	0.02	0.03	0.03	0.02	0.7
Ti	0.66	0.71	0.62	0.62	0.9
V	0.01	0.02	0.02	0.01	0.5
Cr	0.11	0.11	0.23	0.19	1.7
Mn	0.89	0.14	1.9	0.15	1.1
Fe	2.4	2.1	20	5.1	2.4
Co	0.004	0.001	0.01	0.004	4.0
Ni	0.16	0.18	0.3	0.17	0.9
Cu	0.47	0.52	0.77	0.65	1.3
Zn	2.7	1.7	6.3	6.6	3.9
Ge	nd	0.004	nd	nd	–
As	0.01	0.002	0.02	0.02	10.0
Se	nd	0.04	nd	nd	–
Br	0.75	1	0.57	1.2	1.2
Rb	0.03	0.03	0.03	0.03	1.0
Sr	0.2	0.11	8.2	0.14	1.3
Y	0.01	0.01	0.01	nd	–
Zr	0.03	0.01	0.01	0.02	2.0
Nb	nd	nd	nd	nd	–
Mo	0.003	nd	0.02	0.01	–

Table 2 continued

Element	Pure heroin (ng/mg)	Pure cocaine (ng/mg)	Heroin bodypacks (ng/mg)	Cocaine bodypacks (ng/mg)	Ratio between pure cocaine and cocaine bodypacks
Ru	nd	0.001	0.001	nd	–
Pd	nd	nd	0.005	nd	–
Ag	0.06	0.07	0.08	0.08	1.1
Cd	0.004	0.01	0.007	0.006	0.6
Sn	0.08	0.06	0.04	3.99	66.5
Sb	0.03	nd	nd	nd	–
Te	nd	nd	nd	nd	–
I	0.24	0.19	0.22	0.16	0.8
Cs	0.001	nd	nd	0.001	–
Ba	32	4.5	25	2	0.4
La	0.07	0.09	0.17	0.47	5.2
Ce	0.02	0.07	0.14	0.48	6.9
Pr	0.002	0.008	0.01	0.006	0.8
Nd	0.01	0.03	0.05	0.019	0.6
Sm	nd	nd	0.008	nd	–
Eu	0.001	0.001	0.001	nd	–
Gd	0.002	0.002	0.006	nd	–
Tb	nd	nd	0.001	nd	–
Dy	nd	0.002	0.002	0.003	1.5
Er	nd	0.001	nd	nd	–
Tm	nd	nd	nd	nd	–
Yb	nd	0.001	nd	0.001	1.0
Lu	nd	nd	nd	nd	–
Hf	nd	nd	0.001	nd	–
Ta	0.02	nd	nd	nd	–
W	nd	0.002	0.002	0.001	0.5
Re	0.001	nd	0.001	nd	–
Os	nd	nd	nd	nd	–
Ir	nd	nd	0.001	0.001	–
Pt	nd	nd	0.001	nd	–
Au	0.001	nd	nd	0.001	–
Hg	0.03	0.04	0.01	0.02	0.5
Tl	nd	nd	nd	nd	–
Pb	0.21	0.2	0.3	0.21	1.1
Bi	0.003	0.004	0.01	0.001	0.3
Th	0.001	nd	nd	0.001	–
U	0.001	0.001	0.007	0.001	1.0

nd not detected

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